COLORADO RIVER WATER
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Hydrology, Science and Policy

Future Scenarios for the Colorado River

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Introduction

The Colorado River drains 242,000 square miles of the Southwestern United States from Wyoming to the Gulf of Baja California. The basin includes seven states. The river has its headwaters in the Wyoming and Colorado Rocky Mountains, but most of its drainage area is desert with an average annual precipitation of approximately 12" per year or less. The early development of the river was driven by the demand for water to irrigate new lands, provide water supply reliability for existing lands under irrigation, control the periodic large floods that devastated the Imperial Valley in the early 1900s and provide hydroelectric power for the economic development of the region.

Today, the river is also a major source of municipal water for the urban centers within each of the seven Basin States: Cheyenne, Wyoming; the Wasatch Front in Utah; Colorado's Front Range corridor from Ft. Collins to Pueblo, including Denver and Colorado Springs; Santa Fe and Albuquerque, New Mexico; Las Vegas, Nevada; the Tucson and Phoenix metropolitan areas, and the Southern California coastal plain are all major urban areas that receive a significant portion of their water supplies through projects that divert water from the mainstem or major tributaries of the Colorado River.

Growth rates in the States of Nevada, Utah, Colorado, New Mexico and Arizona are all among the highest in the Unites States. Providing secure long-term water supplies for the growing urban centers is one of the most difficult public policy problems facing the Southwest Region.

While often considered one of the nation's great river systems, compared to other great rivers, the flow, or annual discharge, of the Colorado River is quite small. For example, both the Colorado River and Columbia River drain a similar sized land area, approximately 250,000 square miles (650,000 square kilometers). However, the discharge of the Columbia River at its mouth is approximately 13 times that of the Colorado River.[1] The Hudson River, which drains a small fraction of land in comparison to the Colorado, only 13,000 square miles, discharges approximately the same as the Colorado.[2]

Until the recent dry period that began in 2000, there was very little public or even water agency concern with the long-term water supply available on the Colorado River. After the construction of Hoover Dam in the 1930s and Glen Canyon Dam in the 1960s, the river has been fully regulated in all but the wettest of years. The 1950s drought and the filling of Lake Powell, beginning in 1964 and ending in 1980, resulted in declines in storage levels in Lake Mead, but wet years quickly recharged the system putting Lake Mead into a flood control mode from 1983 to 1987. A modest five year drought in the Upper Basin from 1988 to 1992 reduced levels at Lake Powell to about 13 million acre feet (maf), but the wet years in the mid-1990s again refilled both Lake Powell and Lake Mead.

The impacts of the current drought have been significant throughout the basin. The levels of Lake Mead and Lake Powell serve as excellent barometers to gauge the extent of the current drought. According to the daily storage data available on the Bureau of Reclamation's Upper Colorado Region website, on January 13, 2005, Lake Powell contained 8,607,496 acre-feet of storage (34.8% of capacity). The last time Lake Powell was this low was mid-May 1969, during the initial fill of the reservoir. On January 5, 2005 Lake Mead was at an elevation of 1,130' (approximately 14,300,000 acre feet of storage). Since its initial fill, Lake Mead has only twice been below this level. In April of 1956, at the end of the 1950s drought, the reservoir reached a low of 1,083' (about 9,000,000 acre feet of storage) and then again in December 1964, the reservoir reached a low of 1,088'.[3] Since January 5th, the wet weather conditions in the Southwest have actually allowed Lake Mead to gain 7' of elevation (to 1,137'). However, the February 2005 24 month study forecast predicts that Lake Mead will continue to drop reaching 1,108' (or 12,200,000 acre feet) by July 2006.

The situation today offers new challenges. The demands for Colorado River water in both the Upper and Lower Basins are much higher than during the recovery periods following the 1950s and even the 1988 to 1992 droughts. The current drought has opened our eyes to both new and past studies that suggest the twentieth century, especially the first and last quartiles, may have been a period where precipitation and river flow throughout the Colorado River Basin were abnormally high. Could it be that our perception of a drought is based on the experience of exceptionally high flows and thus what we now call "drought" is actually more of a "return to normal"?

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[1]Fritz van der Leeden, "Water Resources of the World, Selected Statistics," TABLE 5-72.

[2]Fritz van der Leeden, "Water Resources of the World, Selected Statistics," TABLE 5-72. This table ranks U.S. rivers in order of discharge at the mouth. The Colorado is ranked #25, between the Illinois River #24 and the Hudson River #26.

[3]The elevation of Lake Mead beginning in the 1930s can be viewed on the Reclamation Lower Colorado River Region website www.usbr.gov/1c/region.

In the Fall of 2004, representatives of the Upper Basin States wrote a letter to the Lower Basin States raising the longstanding and unresolved questions concerning the Upper Basin's obligation to Mexico under the 1922 Colorado River Compact. The Secretary of the Interior has challenged the seven Basin States to get together and address critical drought issues, including the development of formal shortage criteria for delivery of water to mainstem users below Lake Mead when there is insufficient water to deliver 7.5 maf. Within Colorado, an informal group of water attorneys are meeting with the Director of the Department of Natural Resources and the State Engineer to discus of the implications to Colorado of a possible water call under the 1922 compact and the 1948 Upper Colorado River Basin Compact.

The mere mention of the term "compact call" is a frightening thought. It implies three major principles:

1. Many unresolved technical and legal issues associated with the Law of the River will first have to be resolved; Just two examples are the previously mentioned Mexican Treaty obligation for the Upper Basin and therefore the related need for detailed system-wide accounting of the Colorado River, including all tributaries, of water availability and consumptive uses.

2. There will actually be administration of water rights in seven different states on an <u>interstate</u> basis. Within Colorado, water rights administration is routine. It has been necessary for more than 100 years. But within other states, actual water rights administration has never occurred.[4]

3. Finally, if a call were to occur, it would clearly mark the end of the era of the development of new Colorado River water supplies. The paradigm shift that occurred in California with the implementation of the 4.4 plan would happen throughout the basin. Economic development and growth within the basin would obviously continue, but the water to support this growth would have to be supplied by transfers from existing uses, conservation and new technologies.

I do not believe that a Colorado River Compact call is anywhere close to a physical reality. The resolution of the unresolved legal issues will likely take years, probably more than a decade. As of February 1st, there was over 23 million acre-feet of storage in Lake Mead and Lake Powell. And finally, the Upper Basin States are still running a healthy surplus of deliveries at Lee Ferry. The latest Annual Report of the Upper Colorado River Commission reports that the 10-year total of flow at Lee Ferry for the period ending with water year 2003 was 102,451,000 acre feet.[5]

A more serious policy problem for the basin may be a return to normal or status quo "attitude." As of early February 2005, the snowpack above Lake Powell was well above average and the February 1, 2005

[4] The Upper Basin may argue that before a call can be implemented, the Lower Basin will have to curtail the so-called illegal diversions along the Colorado River and possibly unadjudicated surface water rights on the tributaries such as the Verde River in Arizona.

[5] Fifty-Fifth Annual Report of the Upper Colorado River Commission, TABLE 4.

inflow forecast was 115% of normal.[6] In late December 2004 and early 2005, flooding conditions were prevalent on the Lower Basin tributaries, the Verde, Virgin and Bill Williams Rivers.

Perhaps the drought is over, or perhaps 2005 will be followed by continuing dry years. No one knows for sure.

The Hydrology of the 1922 Compact

Much has been written about the hydrologic basis of the 1922 compact. The bottom line is that based on a very limited amount of technical information available to them, the negotiators believed that there was at least 17.2 million acre feet (maf) per year available at Lee Ferry.[7] Whether one uses the gauge record or a longer record based on tree ring analysis, the period from about 1905 to 1925 was a period of abnormally high flows. Figure 1 shows the 15 year running average undepleted (aka virgin) flow at Lee Ferry based on the gauge records.[8] Figure 2 shows the 15 year running average undepleted flow at Lee Ferry based on a 450 year reconstruction of the flow at Lee Ferry from tree ring analysis. Both graphs clearly show that the first quarter of the twentieth century was very wet.

[6]National Weather Service, Colorado River Basin Forecast Center, Salt Lake City, Utah, February 1st 2005 forecast Normal April to July inflow is about 7.8 maf.

[7]The minutes and record of the first eighteen sessions of the Colorado River Commission. These minutes suggest that the compact negotiators were not concerned about virgin flows. Minutes of the sixth meeting, page 73, reports the average actual flow at Yuma was 17,300,000 a.f/year. The commission derived their estimate of the virgin flow at Lee Ferry by assuming 86% of the Yuma flow was from above Lee Ferry (minutes of the eighth meeting, page 23). This equals 14,964,000 a.f. Adding back upstream depletions, Table A, page 70, of 2,267,000 a.f. makes a total flow at Lee Ferry of 17.23 maf per year.

[8] The source for the undepleted flow data at Lee Ferry is the Upper Colorado River Commission. A running average (sometimes referred to as a smoothed average) is simply the average of the previous 10 years.

Figure 1
10 Year Running Average
Undepleted Flow at Lee Ferry

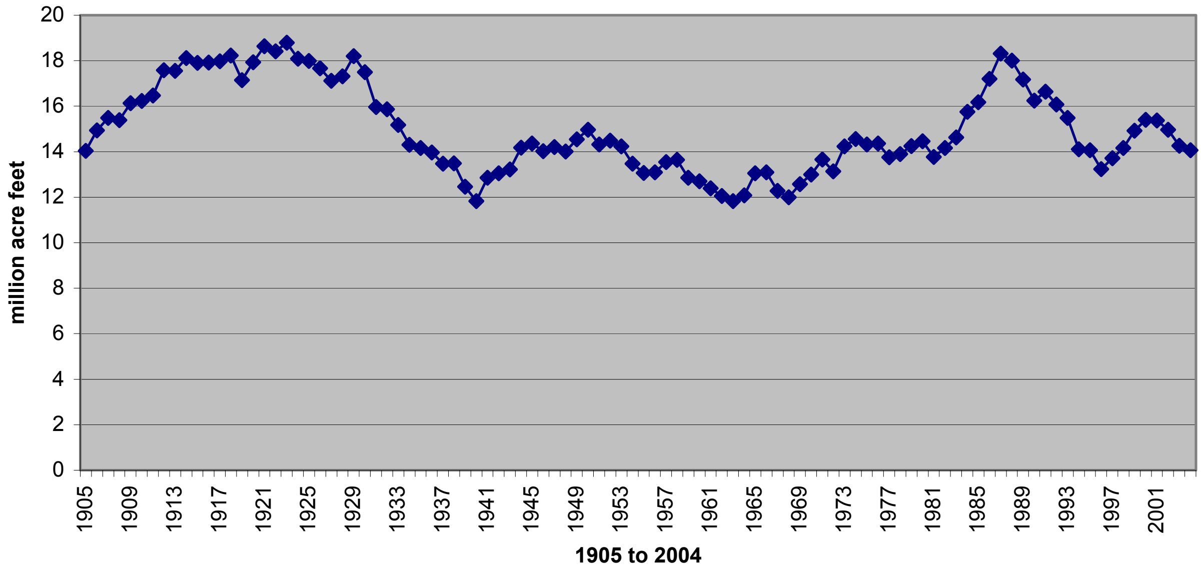

Figure 2
15 Year Running Average
Colorado River at Lee Ferry

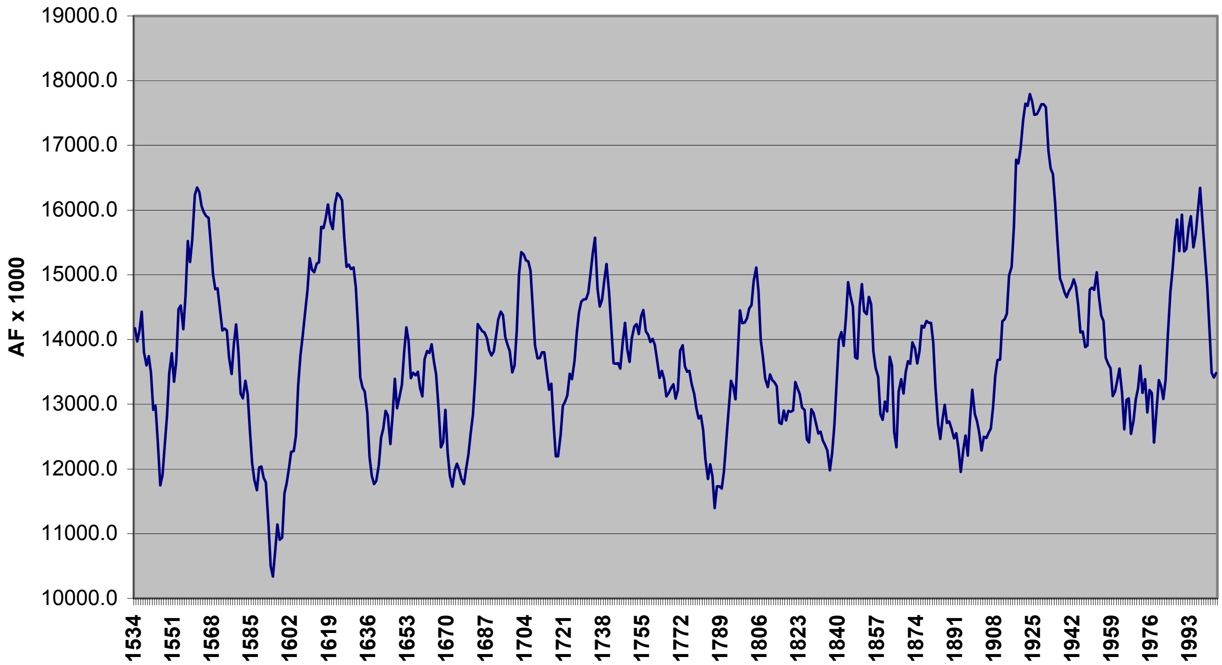

Figure 2 is based on data provided by Benjamin Harding of Hydrosphere Inc. The data from 1534 to 1961 is derived from dendrochronology (tree rings). For the period from1961 to 2004, the source of the data is Upper Colorado River Commission. The highest peak on Figure 2 (about 1924) occurred about the same time as the negotiations for the 1922 compact.

The hydrology provisions of the 1922 compact are contained in Article III. Article III (a) apportions in perpetuity to both the Upper and Lower Basins the exclusive beneficial consumptive use of 7.5 maf per year. Article III (b) provides that in addition to the 7.5 maf per year of consumptive use provided for in III (a), the Lower Basin is given the right to increase its beneficial use by 1 maf per year. Note that the language uses the word "increase." Thus, the compact contemplates the use of up to 16 maf per year, 8.5 maf for the Lower Basin and 7.5 maf for the Upper Basin.

Article III (c) of the compact anticipated a treaty with Mexico which, in fact, was completed in 1944. Article III (c) provides that water for Mexico "shall be supplied first from the waters over and above paragraphs (a) and (b); and if such surplus shall prove insufficient.... the burden .... shall be equally borne by the upper basin and the lower basin and the upper division states shall deliver at Lee Ferry water to supply (its obligation) .... in addition to that provided in paragraph (d)."

Note that the waters in paragraphs (a) and (b) total 16 million acre feet, but there is no mention as to how such a surplus is calculated. Is it based on the system water that would have been available to Mexico at the border near Yuma? Alternatively, is it measured at the points of use on the tributaries and mainstem?

How is mainstem reservoir evaporation on Lake Mead, Lake Mohave, Lake Havasu and the Colorado River Storage Project (CRSP) reservoirs accounted for? Is it considered an Article III (a) depletion in the appropriate basin?

Article III (d) provides that the "states of the upper division will not cause the flow.... at Lee Ferry to be depleted below 75 maf for any ten consecutive years." Note that this provision does not guarantee a flow of 75 maf, it only prevents the Upper Basin from causing the flow to go below this figure. The prevailing assumption is that a call could occur if the Upper Basin States were ever to violate Article III (d).

Three other provisions of the 1922 compact are also relevant to the question of a future compact call. Article III (e) requires that "the states of the upper division shall not withhold water and the states of the lower division shall not require the delivery of water, which cannot reasonably be applied to domestic agricultural uses." Could the Lower Basin impose a call on the Upper Basin to charge groundwater basins or to maintain an elevation at Lake Mead above Southern Nevada's intake structure? Likewise, could the Upper Basin withhold water in Lake Powell for the primary purpose of maintaining powerhead?

The compact defines the Colorado River system in Article II (a) as "that portion of the Colorado River and its tributaries within the United States." Also, Article IV (b) provides that "(p)resent perfected rights to the beneficial use of waters of the Colorado River system are unimpaired by this compact." The most common interpretation of this provision is that it applies to rights perfected by use prior to November 24, 1922. An argument could also be made that it applies to rights prior to June 15, 1929 based on the Boulder Canyon Project Act which provided for a six state ratification of the compact.[9]

Other Provisions of the Law of the River

In addition to the 1922 Colorado River Compact, a number of other compacts, federal and state laws and court decrees comprise what is commonly referred to as the Law of the River.

The 1944 international treaty with Mexico provides an annual delivery to Mexico of 1.5 maf per year. It also includes provisions to provide an additional 200,000 acre feet per year when there is a surplus and allows the United States to reduce deliveries during an "extraordinary drought."

The 1948 Upper Colorado River Basin Compact apportions the Upper Basin's share of the 1922 compact as follows:[10]

- 50,000 acre feet per year to Arizona, with the remainder:
- 51.75% to Colorado
- 23.00% to Utah
- 14.00% to Wyoming

[9]This argument might be based on the fact that the decree in Arizona v. California defines perfected rights as those in use prior to June 15, 1929.

[10] Note that the Upper Basin compact negotiators decided to divide up the available water by a percentage allocation, not specific amounts of water in acre-feet.

- 11.25% to New Mexico

The 1928 Boulder Canyon Project Act authorized the construction of Hoover Dam and the All American Canal, provided for a six state ratification of the 1922 compact and contains provisions that became the basis for apportionments of mainstem water to the three lower division states under the 1964 Arizona v. California Supreme Court decrees.

The 1956 Colorado River Storage Project Act, the 1968 Colorado River Basin Project Act and the 1964 decree in Arizona v. California all provide critical provisions that control the operation of Lake Mead and Lake Powell and control the delivery of water from federal projects to water users throughout the Basin States.

Current Operation of Lake Mead and Lake Powell

Operations of the two major mainstem reservoirs (Lake Mead and Lake Powell) are governed by the Law of the River. The Secretary of the Interior prepares and promulgates an annual operating plan (AOP).[11] Reclamation prepares the AOP in an open public process in close cooperation with the Basin States. The AOP is typically prepared during the summer and fall prior to the year of its implementation.

The operation of Lake Mead is complex, but as a general rule, its water operations are governed by the amount of water in storage in the reservoir and the anticipated inflow. If an ample supply is available, it is considered a surplus year and if the demands require, more than 7.5 maf of water can be delivered to the three Lower Basin States and up to 1.7 maf to Mexico. The Secretary of the Interior has promulgated interim surplus guidelines (ISGs) which govern the actual surplus amounts available based on storage level triggers in Lake Mead.[12] If only an "average" amount of water is available, it is considered a "normal" year and 7.5 maf is made available to the states and 1.5 maf to Mexico. The ISG normal year elevation trigger is 1,125' or about 13.8 maf of storage.

If the water supply is very low, the Secretary has the authority under the 1964 decree to declare a shortage and deliver less than 7.5 maf to the Lower Basin States and under the 1944 treaty to possibly reduce deliveries to Mexico to less than 1.5 maf.[13] There are currently no shortage criteria. Developing consensus shortage criteria is one of the major challenges facing the Basin States. The development of shortage criteria is complicated by the 1968 Colorado River Basin Act, which for all practical purposes, places the entire burden of a shortage on the Central Arizona Project and the water supply available to Las Vegas.[14]

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[11]Current and past AOPs can be viewed on either the Upper or Lower Colorado Region websites: www.usbr.gov/ucor lc

[12]The interim surplus guidelines can be viewed on the Lower Colorado Region website: www.usbr.gov/lc

[13]See the decree in Arizona v. California, 376 U.S. 340, the decree actually uses the term "sufficient" and "insufficient."

[14]The policy of the Central Arizona Project governing board on the CAP priority can be viewed at www.CAP.az.com/briefings/priority

The operation of Lake Powell is not quite as complex as Lake Mead. In general, Lake Powell and the other CRSP reservoirs are governed by what is referred to as the "Long Range Operating Criteria.[15] From the Upper Basin perspective, there are two critical provisions of the Long Range Operating Criteria. The first is a "602(a) storage" trigger which determines when equalization releases from Lake Powell to Lake Mead occur.[16] The second is a minimum objective release amount of 8.23 maf per year. The 8.23 maf per year consists of average 7.5 maf per year delivery pursuant to Article III (d) of the 1922 compact, plus 750,000 acre feet per year for 1/2 of the Mexican Treaty obligation, less 20,000 acre feet per year, the estimated average flow of the Paria River. The Paria is an Upper Basin tributary that enters the Colorado River between Glen Canyon Dam and Lee Ferry.

The Upper Basin States have consistently objected to including the 750,000 acre-feet delivery to Mexico in the calculation of the minimum objective release. The Upper Basin position is emphatically that under the 1922 compact, it must deliver 1/2 of the treaty obligation if, and only if, there is no available surplus of "waters over and above paragraphs (a) and (b)."

Thus, under the current, but disputed, operations, Lake Powell releases will either be 8.23 maf per year or a greater amount if Lake Powell storage levels are above the 602(a) trigger. Additional releases can also be made when either reservoir is approaching full conditions under a fill-without-spill policy at Lake Powell or under the flood control operations at Lake Mead.[17]

Current Status of Water Use on the Colorado River

Every five years, the Secretary of the Interior publishes the Colorado River System Consumptive Uses and Losses Report. The most recent report covering 1996-2000 was just recently published as a final report. Data from the Consumptive Uses and Losses Report is now available from 1971 to 2000.[18] This data presents a clear picture of the water use trends throughout the basin.

Figure 3 shows the total uses by the Upper Basin from 1971 to 2000. The totals include Arizona's Upper Basin use and CRSP evaporation. The figure includes a simple trend line.

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[15]The long range operating criteria can be viewed on either the Upper or Lower Colorado Region websites: www.usbr.gov/uc or lc

[16]Under the ISGs, the interim 602(a) level has been set at 14.85 maf of storage in Lake Powell.

[17]The generation of hydroelectric power is an important consideration in the operation of both Lake Mead and Lake Powell. At Powell, power generation can affect the daily, weekly and sometime monthly release schedule, but does not affect annual deliveries. Releases from Lake Mead are dictated by the water demands but with Lake Mohave serving as a re-regulating reservoir for power operations, releases through the power plant are used for load following.

[18]The Consumptive Uses and Losses Report is prepared pursuant to the Colorado River Basin Project Act of 1968, Public law 90-537. The act directs the Secretary to "make reports as to the annual consumptive uses and losses of water from the Colorado River System after each successive five year period starting on October 1, 1970." The latest report available covers the 1996-2000 period. The report may be obtained from either the Upper or Lower Colorado Regions.

Figure 3
Total Upper Basin Uses

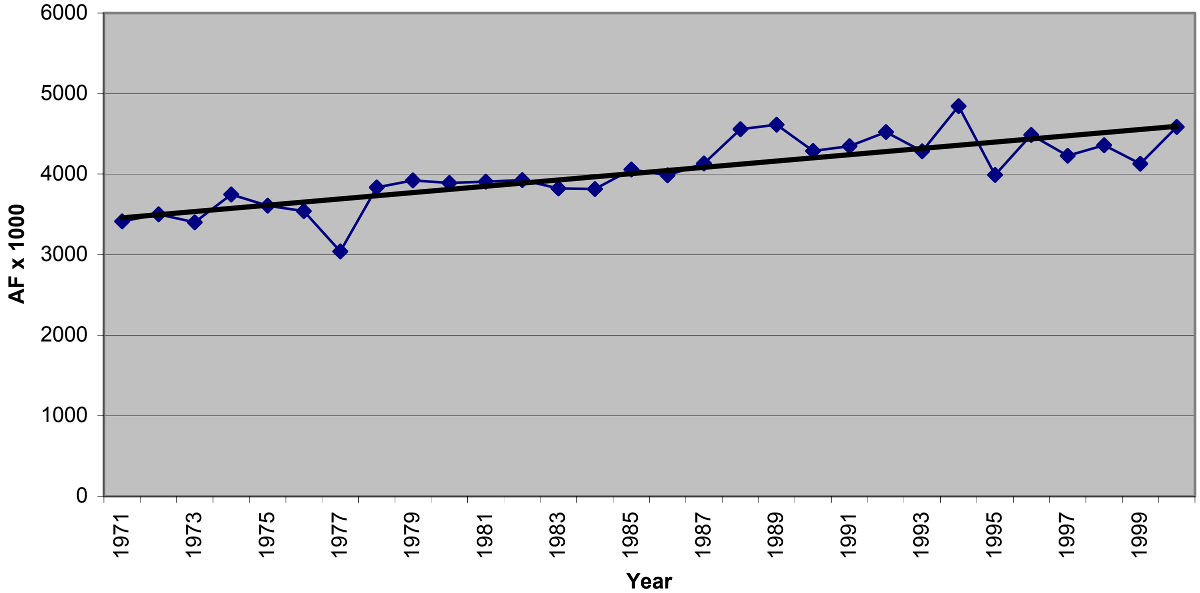


Figure 4 shows total uses by the State of Colorado from 1971 to 2000, including Colorado's share of CRSP evaporation. Both Figure 3 and Figure 4 show a clear upward trend. The trend line is included on the graph.

Figure 4
Total Colorado Uses

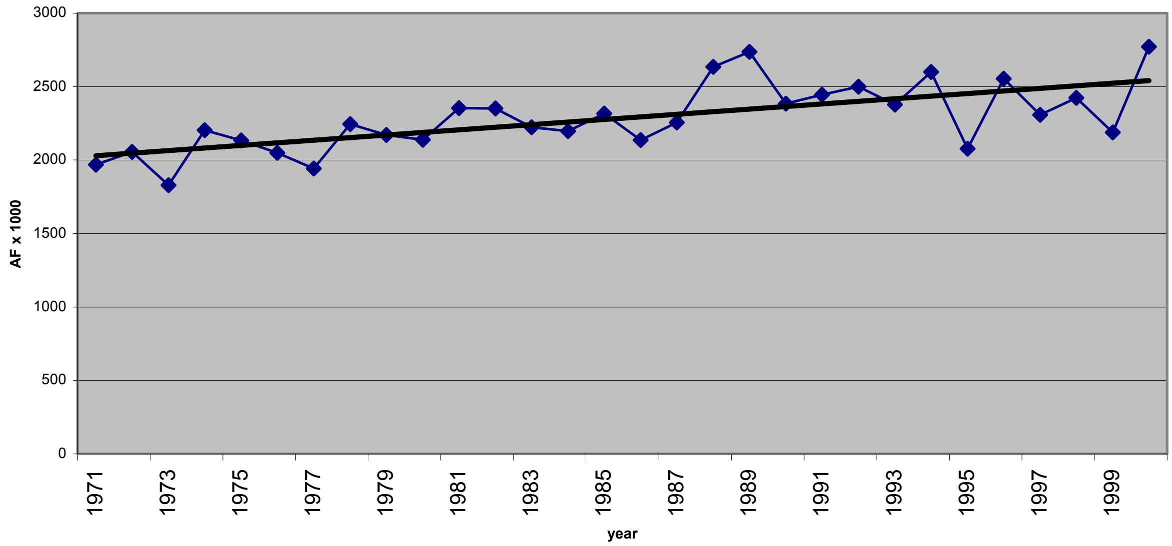


Figure 5 shows mainstem deliveries to Arizona. One can clearly see the impact of the completion of the Central Arizona Project. With water banking, Arizona now has a demand for its full 2.8. maf normal year apportionment.

Figure 5
Mainstem Deliveries to Arizona

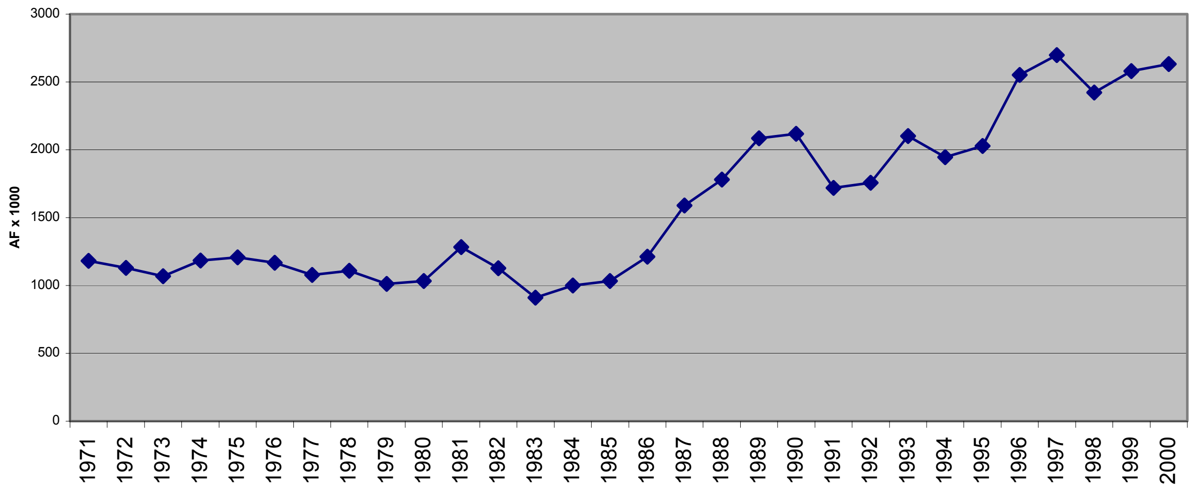


Figure 6 shows deliveries to Nevada, again one can clearly see the impact of growth in the Las Vegas Valley.
The graph includes tributary use. Nevada is now at a demand for its full 300,000 acre-feet normal year mainstem apportionment.

Figure 6
Total Nevada Uses Including Tributaries

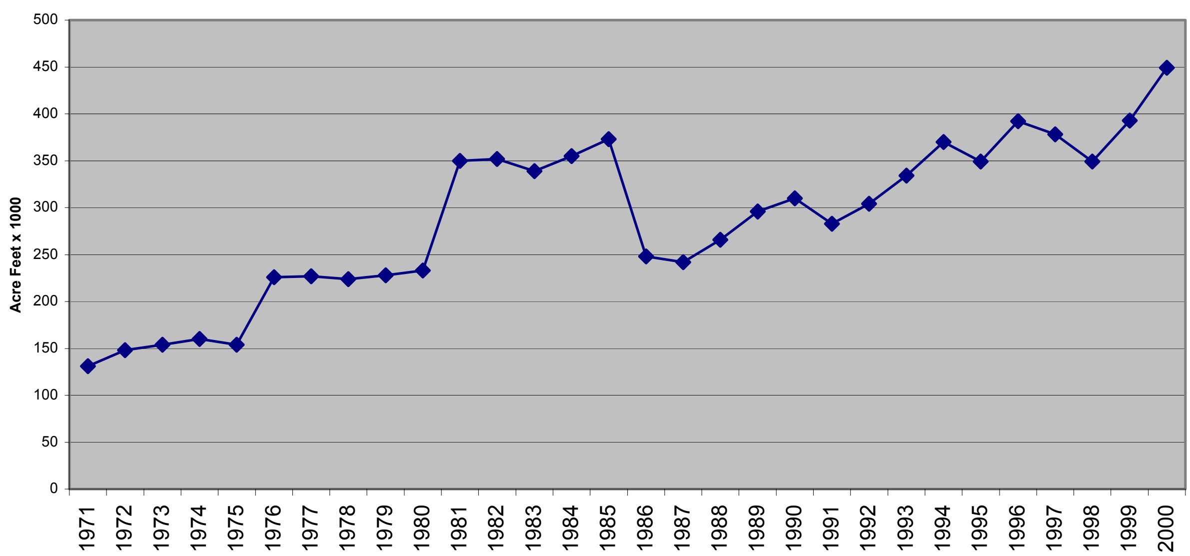


Figure 7 shows mainstem deliveries to California. The California agencies have a demand for over 5.0 maf, but a normal year apportionment of only 4.4 maf/year.

Figure 7
Mainstem Deliveries to California

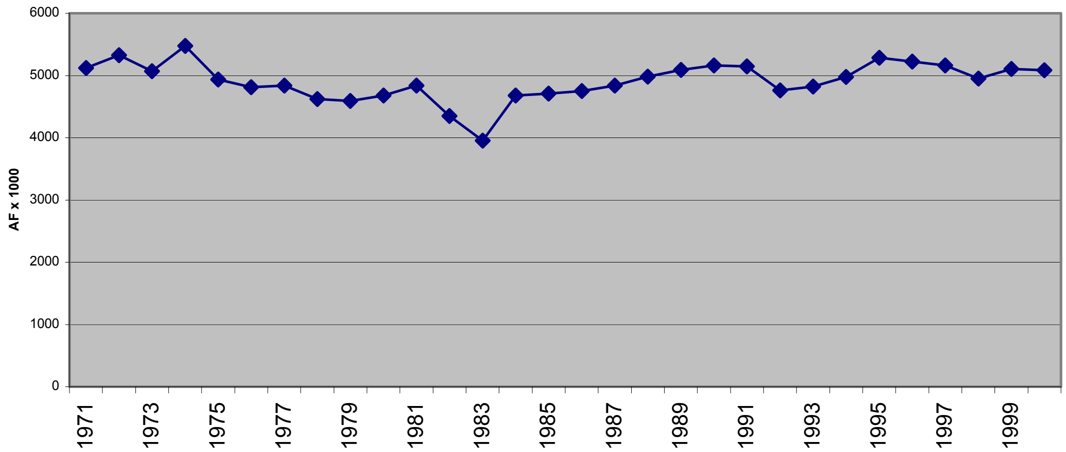


Figure 8 shows tributary uses in Arizona. The Consumptive Uses and Losses Report text states that it includes both tributary uses and groundwater overdrafts and that Interior does not have necessary data available to separate the two. One can easily see the impact of Arizona's efforts to manage groundwater beginning in the early 1980s.

Figure 8
Tributary Use In Arizona

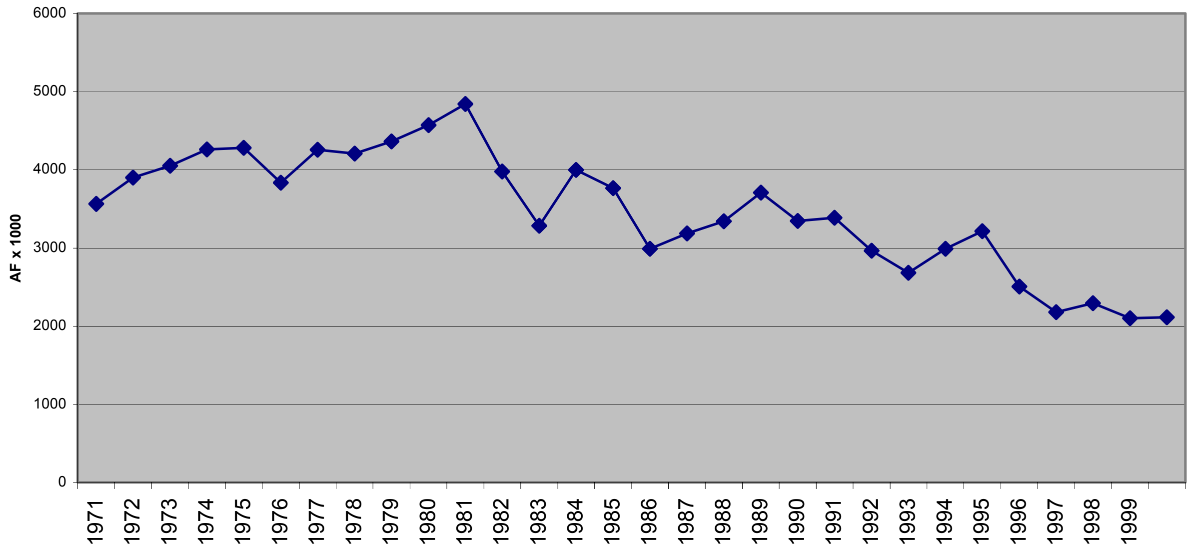


Figure 9 shows deliveries to the Republic of Mexico.

Figure 9
Deliveries to Mexico

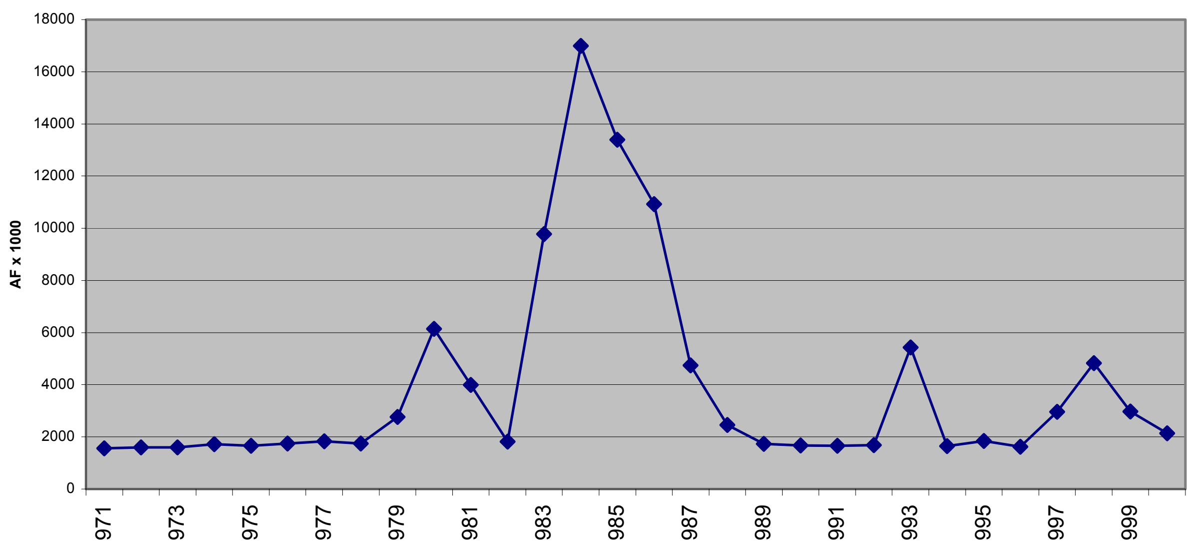
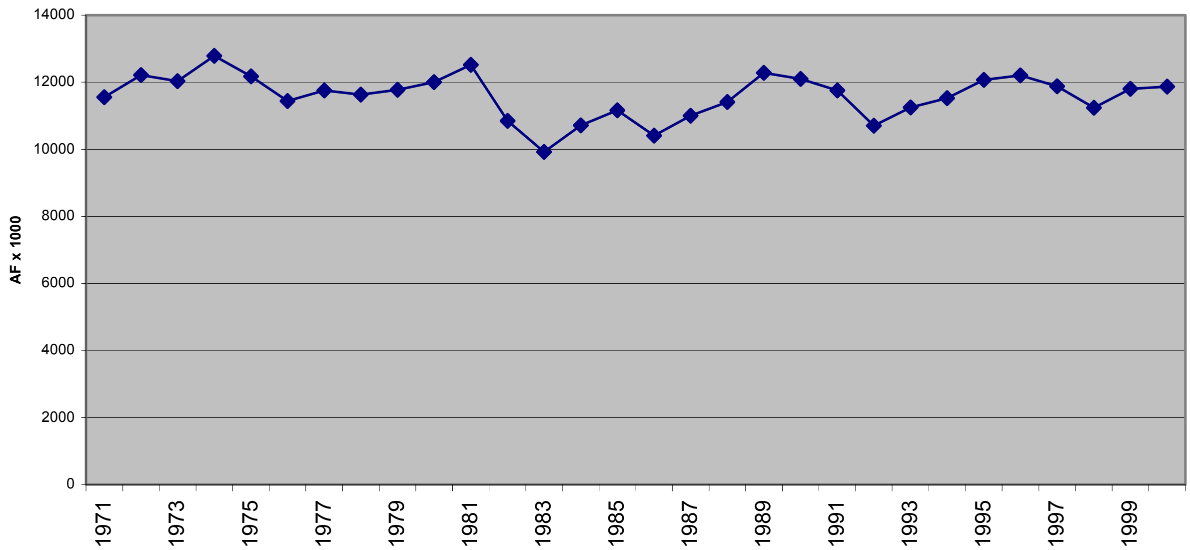


Figure 10 shows total Lower Basin uses, including mainstem reservoir evaporation and system losses. Again, because the tributary data includes groundwater overdrafts, the annual totals probably overstate the actual annual surface water use.

Figure 10
Total Lower Basin Uses Including Groundwater Overdrafts and System Losses



The conclusions I make from these figures are:

1. The current demand for and use of Colorado River water in the Upper Basin is in the range of 4.5 to 5.0 maf per year including CRSP evaporation. It is in the range of 4.0 to 4.5 maf per year excluding CRSP evaporation.

2. The current demand for Colorado River water on the Lower Basin mainstem for consumptive uses excedes 8.0 maf per year, but the available normal year supply is only 7.5 maf per year. Full demands can only be met when there is a surplus.

3. Including reservoir evaporation, system losses and deliveries to Mexico, which collectively total 2.5 to 3.0 maf per year, the normal year demand on Lake Mead is 10.0 to 10.5 maf per year.

4. Because these data include groundwater overdrafts, it is difficult to make any conclusions concerning the level of Lower Basin tributary use, but even if Lower Basin tributary use was only 1.0 maf per year, total Colorado River system use in the Lower Basin, including reservoir evaporation, but excluding deliveries to Mexico probably now exceeds 8.5 maf per year in most years.

Estimates of the Water Supply Available on the Colorado River System
One of the most critical and confusing questions facing Colorado River policymakers is also one of the most basic; what is the long-term reliable water supply available from the Colorado River?

As previously discussed, the Colorado River Compact negotiators in the early 1920s assumed there was an average undepleted flow of at least 17 maf per year available at Lee Ferry. Almost all of the technical studies completed since the compact was ratified have reduced this estimate. It is important to remember that all of the studies provide engineering "estimates" of the undepleted flow. The first gauge was not installed at Lee Ferry until the spring of 1921. By that time, upstream depletions were already impacting the flow. Thus, undepleted flows are determined by adding estimated upstream depletions to the gauge record. The accuracy of the undepleted flow calculation is impacted by both the accuracy of the gauge and the accuracy of the estimates of upstream depletions.

By 1947, when the Bureau of Reclamation issued House Document 419, 80th Congress 1st Session, a comprehensive report on the development of the Colorado River, the estimated average undepleted flow at Lee Ferry was 16.4 maf per year.[19]

In 1965, the Denver engineering firm of Tipton and Kalmbach, Inc.[20] issued a report for the Upper Colorado River Commission titled "Water Supplies of the Colorado River." By the time the Tipton report was completed, the hydrologic discussion had turned from focusing on long-term average supplies to considering the critical low periods within the longer term record. Tipton concluded that "no matter what periods between 1896 and 1964 are used for particular studies, the period of low water supply beginning in 1930 and ending in 1964 cannot be avoided. It would be optimistic to assume a firm water supply any greater than that which existed during the 1930 through 1964 plus whatever water might have been available from holdover storage at its beginning." Based on the UCRC record, the average undepleted flow at Lee Ferry from 1930 to 1964 was right at 13.0 million acre feet.

In the conclusions, Tipton states that "if deliveries at Lee Ferry were 8.25 maf/year, the limit of depletions in the states of the upper division would be 5.6 maf including reservoir evaporation, and a net of 4.7 maf excluding reservoir evaporation." The highest single year use in the Upper Basin as reported by the Consumptive Uses and Losses reports was 1994 when the consumptive use, excluding CRSP reservoir evaporation was 4.245 maf.

Tipton also makes conclusions regarding the available supply to the Upper Basin based on a delivery of 7.5 maf per year. This estimate, excluding reservoir evaporation is 5.6 maf. Tipton went on to make conclusions concerning shortages in the Lower Basin, suggesting that the shortage "will amount to well over one million af by the year 2000."

In 1975, C.W. Stocton and G.C. Jacoby published their groundbreaking work estimating the long-term flow of the Colorado River system on analysis of the tree ring record. This report concluded that the long -term mean depleted flow of the Colorado River at Lee Ferry is 13.5 $\pm$ .5 maf per year.[21] Stocton and

[19]United States Department of the Interior, The Colorado River, House Document 419, 80th Congress 1st Session, July 1947, see Table CXL, page 281.

[20]Tipton and Kalmbach, Inc, "Water Supplies of the Colorado River," July 1965. Prepared for the Upper Colorado River Commission. This report is not readily available, but copies are available in the libraries of the Colorado Water Conservation Board, Denver, Colorado and the Colorado River Water Conservation District, Glenwood Springs, Colorado.

[21]Stocton, Charles W., and Gordon C. Jacoby, Jr., "Long-Term Surface-Water Supply and Stream Flow Trends in the Upper Colorado River Basin," March 1976.

Jaocby also gave us an opportunity to examine the long term record and evaluate the drought periods experienced in the 1930s and 1950s against a longer term record.

Figure 11
Undepleted Colorado River Flow at Lee Ferry
Running 30 year average

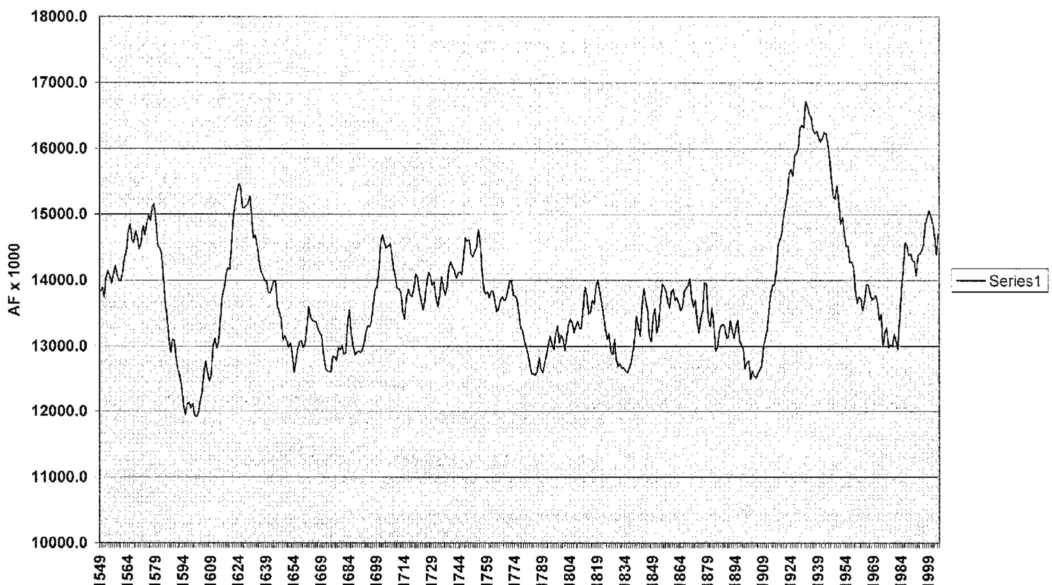


Figure 2 shows the running 15 year average of the undepleted flow at Lee Ferry from 1534 to 2004. Figure 11 shows the running 30 year average. Because of the large amount of system storage, the 30 year running average is a very meaningful statistic. Based on the tree ring record, the droughts of the 1900s were relatively mild compared to those seen in previous centuries.[22] Figure 11 shows six historical drought periods where the 30 year running average dropped below 13 maf/year. The most significant of these occurred in the late 1500s.

The Stocton and Jacoby data was also used as the basis for the severe and sustained drought project. The results of this project were published in the October 1995 Journal of the American Water Resources Association.[23]

In 1988, the Department of the Interior issued what is commonly referred to as the "Hydrologic Determination." The long title of the report is "Water Availability from Navajo Reservoir and the Upper

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[22]The reconstructed flow data at Lee Ferry was provided by Benjamin Harding of Hydrosphere, Inc. These are the same flows Mr. Harding used in "Impacts of a Severe Sustained Drought on Colorado River Water Resources" which is included in Footnote 21.

[23]Water Resources Bulletin, American Water Resources Association, October 1995. The entire journal is dedicated to the results of "coping with severe sustained drought in the Southwestern United States."

Colorado River Basin for Use in New Mexico." The report was formally approved by the Acting Secretary of the Interior on February 2, 1989.[24]

The 1988 report superceded a similar 1984 report. The bottom line is that Reclamation concluded that "water depletions for the Upper Basin of the Colorado River can be reasonably allowed to rise to 6 maf/year." The Executive Summary of the report also notes that "to avoid a critical compact interpretation, we assume that the Upper Basin will be obligated to deliver 7.5 maf of water every 10 years at Lee Ferry, plus 750,000 acre-feet annually toward Mexican Treaty deliveries." Another critical assumption in this study is that Lake Powell is considered empty at the minimum power head elevation.

The 1988 study used an 81-year period from 1906 to 1986. The mean undepleted flow at Lee Ferry for this 81-year period is approximately 15.2 maf per year.

Finally, the latest UCRC annual report includes tables of the estimated virgin flow at Lee Ferry from 1896 through 2003. The mean undepleted flow at Lee Ferry for this 108-year period is 14.8 maf per year. [25]

A Summary of Recent Science Articles that may be of Interest to the Colorado River Basin

There are a number of recent scientific papers published that I believe provide additional insight on the possible problems. For convenience, I have listed a number of the articles I reviewed and which, as a water manager, I believe may be relevant to the future of the Colorado River:

1. "Climate Precursors of Multidecadal Drought Variability in the Western United States"; Hugo G. Hidalgo, Climate Research Division, Scripps Institute of Oceanography, University of California, San Diego. Accepted with Revisions; Water Resources Research; July 2004.

2. "Patterns and Sources of Multidecadal Oscillations in Drought-Sensitive Tree-Ring Records from the Central and Southern Rocky Mountains"; Steven T. Gray, Julio L. Betancourt, Christopher L. Fastie and Steven T. Jackson; Geophysical Research Letters, Vol. 3o, 2003.

3. "Decreasing Reliability and Increasing Synchroneity of Western North American Stream Flow"; Shaleen Jain, Martin Hoerling and Jon Eischeid; NOAA-CIRES Climate Diagnostic Center, Boulder, CO.

4. "As the West Goes Dry"; Robert F. Service; Science Magazine, Vol. 303, February 20, 2004.

5. "Pacific and Atlantic Ocean Influences on Multidecadal Drought Frequency in the United States"; Gregory J. McCabe, Michael A. Palecki and Julio L. Betancourt; PNAS, March 23, 2004 Vol. 101, No. 12.

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[24]United States Department of the Interior; "Water Availability from Navajo Reservoir and the Upper Colorado River Basin for Use In New Mexico," February 2, 1989.

[25]See footnote #5, table 3.

6. “A 431-Year Reconstruction of Western Colorado Snowpack from Tree Rings”; Connie A. Woodhouse; Journal of Climate, Vol. 16, May 15, 2003.

7. “Relationships Between New Mexico Precipitation, the Atlantic Multi-Decadal Oscillation and Pacific Decadal Oscillation”; Charles A. Liles, National Weather Service, Albquerque, April 2004.

8. “The Affects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin”; Niklas S. Christensen, Andrew W. Wood, Nathalie Voisin, Dennis P. Lettenmaier and Richard Palmer; Climatic Change 62: 337-363, 2004.

As a water manager, my review of these articles leads me to believe that we may be entering into a new era on the Colorado River where the future hydrology cannot be reasonably estimated by simply using the available gauge record. Alternately, it is possible that selected periods from the gauge may be more relevant to the future than others. McCabe, Palecki et al. and Gray; Faste and Jackson all suggest the extended periods of wet and dry cycles we see in the long term hydrologic record can, in part, be explained by low frequency (long period) changes in ocean temperatures. The relationship between the Atlantic Multidecadal Oscillation (AMO) and the occurrence of drought in the Western United States is intriguing. There is a statistical correlation between the frequency of drought within the Colorado River Basin and a positive AMO index. The AMO went negative in the early 1900s and stayed negative until about 1930. The index then turned positive and stayed positive until about 1965. The next negative period lasted until the mid 1990s when it again turned positive. Continuing this pattern, the AMO index could stay positive until 2020 or 2030. Does this mean that we might expect another 15 to 25 years of generally dry conditions in the Colorado River Basin?

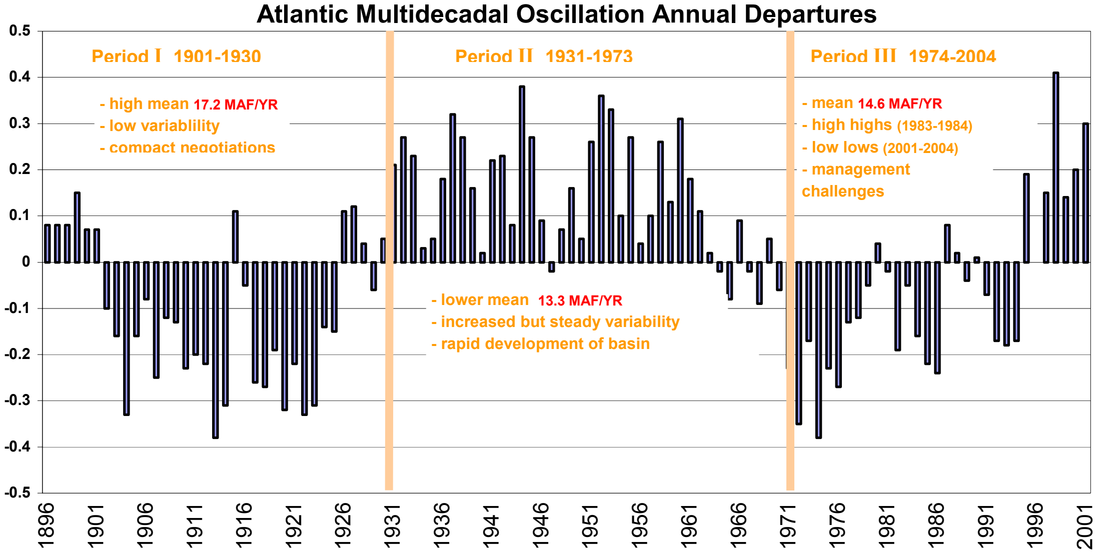
McCabe, Palecki and Betancourt use the AMO, the Pacific Decadal Oscillation (PDO) and average Northern Hemisphere temperatures to help explain multidecadal drought frequencies. This research concludes that “persistence of the current positive AMO state may lead to continuing above normal frequencies of United States drought in the near future.”

Service, and Christensen et al. describe the potential impact of increasing worldwide temperatures (global warming) on the Colorado River. A decrease of basin-wide precipitation by even 10% would have significant impacts throughout the basin. Even if basin-wide precipitation remains the same or increases, a higher percentage of the precipitation would fall as rain. More rain and less snow could advance the snowmelt, reduce overall river discharge, and increase evapotranspiration water demands throughout the basin. The effective water yield of many basin reservoirs could be significantly reduced.

Jain, Hoerling and Eischerd found that the variability of the flows on the Colorado River and three other major rivers, the Fraser, the Columbia and the Sacramento has increased since 1971. Increasing variability suggests a future Colorado River with higher highs and lower lows. This could result in new management challenges, possibly require new reservoir design parameters, decrease the firm yield of existing reservoirs and increase the damage from flooding when it does occur. The increase in synchronous low and high flows means that wet and dry periods across four major rivers are occurring in the same years. This would place the impacts of droughts on much larger portions of the West straining resources for mitigation.

Figure 12 is a graph I prepared for a presentation in Gunnison, Colorado in 2004. The figure shows the AMO departure index and divides the Colorado River guage history into three distinct periods. During period One, the AMO was negative. The mean undepleted flow at Lee Ferry was over 17 maf/year. In the second period (1930 – 1970), the AMO was positive and Average Lee Ferry mean flow was only about 13 maf/year. During the third (1970 – present), the AMO was initially negative, but turned positive in the late 1990s.

Figure 12
Atlantic Multidecadal Oscillation Annual Departures



As the science related to paleoclimate and climate change continues to evolve and improve, the challenge for water management agencies will be to keep in touch with the scientific communities, help direct and fund priorities and consider the consequences of the conclusions on project operations.

I note that within past extended dry periods there were always occasional wet years. 1957 and 1958 were two wet years in the middle of the 1953 to 1964 dry period. Conversely, 1977 and 1981 were very dry years in the middle of the 1972 to 1987 wet period. If 2005 remains wet, it may not be the end of the current drought.

Two Contrasting Scenarios for the Future of the Colorado River
As a conclusion, I will present two contrasting scenarios for the future of the Colorado River Basin. I present these scenarios simply for illustrative and discussion purposes. The principal difference between the two scenarios will be the available water supply at Lee Ferry.

The first scenario will be referred to as the "status quo" scenario. The status quo scenario will be based on the fundamental assumption that the long-term mean undepleted flow at Lee Ferry is about 15 maf per year. As we have seen in the past, river flows will be variable, with the continuation of both wet periods similar to those in the early 80s and mid 90s and periodic droughts such as those seen from 1988 to 1992 and 2000 to 2004.

The second scenario I will refer to is the "alternative" scenario. The alternative scenario will be based on the assumption that the long-term mean undepleted flow at Lee Ferry is closer to 13 maf per year. The hydrology will continue to be highly variable with a few wet periods and longer dry periods.

The Status Quo Scenario

The status quo scenario proceeds as follows: water year 2005 stays relatively wet, 2006 and 2007 provide about average inflow to Lake Powell. Lake Powell storage recovers sufficiently to require a small equalization release in 2006 and a greater equalization release in 2007. At the end of 2007, both Lake Mead and Lake Powell contain about 15 maf of storage.

Limited surpluses are available for California again in 2007. The additional water in storage takes the pressure off the Basin States to develop shortage criteria.

From 2008 through 2012, conditions turn generally dry again, storage levels in both Lake Mead and Lake Powell decline. By 2012 Lake Powell is again approaching minimum power head and Lake Mead is approaching the minimum level for operation of the upper Las Vegas intake (1,050').

The Basin States are again under pressure to agree on consensus shortage criteria. Arizona, Nevada and California cannot agree on consensus criteria, therefore the Secretary of the Interior takes over and proposes interim shortage criteria.

The Upper Basin States again challenge the minimum objective release of 8.23 maf per year at Lake Powell. The Secretary takes the issue under advisement and appoints a technical committee to study the issue and make recommendations concerning the development of basinwide accounting.

Development and use of water in the Upper Basin States continues to increase, but at a slower pace than the levels seen in the last quarter of the twentieth century. Utah begins to permit a pipeline project to deliver water from Lake Powell to the St. George area. The Upper Basin States propose that return flows to the Colorado River via the Virgin River be credited as flow delivered at Lee Ferry.

Colorado and Wyoming continue to develop Colorado River water. The increase in depletion levels in Colorado is primarily caused by the increased diversions and consumptive use by existing projects which are currently not fully utilized. New Mexico finishes the San Juan to Gallup pipeline project.

Within the Lower Basin, Arizona continues to divert about 2.8 maf per year of mainstem water. About 300,000 acre feet per year is diverted by the Central Arizona Project for water banking. California's 4.4 plan is on track, but dry conditions on both the Colorado River and in northern California are making the Metropolitan Water District nervous. Nevada is struggling, but is getting by because of its agreement with Arizona. Las Vegas begins using water from the Muddy and Virgin River Basins and has begun construction of a pipeline to convey groundwater from central Nevada to Las Vegas. Las Vegas extends its intake down to 950' in Lake Mead.

Water years 2013 and 2014 are moderate El Nino years. Lake Powell recovers and approaches 14.85 maf equalization trigger. Arizona, Nevada and California agree to share a 500,000 acre-foot shortage, primarily by additional land fallowing in Arizona.

Water years 2015 and 2016 are La Nina years, but the snowpacks in northern California, northern Colorado and Wyoming are good. Lake Powell continues to recover and begins equalizing. The Secretary of the Interior extends the ISGs for ten more years.

Water years 2017 through 2025 are generally wet. Both Lake Powell and Lake Mead fill. Lake Mead begins making flood releases. In 2022, deliveries to Mexico exceed 10 maf. California declares that it has successfully completed the 4.4 plan, but it still needs about 4.7 maf per year to get by. Arizona has 10 maf in its groundwater bank and Southern Nevada Water Authority's new projects give it an ample supply for its 3 million residents and will allow for growth of another 2 million.

The Alternative Scenario

Precipitation for the remainder of the winter of 2005 is slightly above average. The April to July forecast is for a 9.6 maf runoff into Lake Powell, but a warm dry May and June reduce actual inflow to 8.8 maf. The runoff is still sufficient to increase year-to-year storage in Powell by 3 maf. The Upper Basin States breathe a sigh of relief.

The Secretary delivers 7.5 maf from Lake Mead to the Lower Basin States and about 2.0 maf to Mexico. The higher deliveries to Mexico result from high tributary flows below Lake Mead. .

Lake Mead storage continues to decline, but it only loses about 300,000 acre feet of storage in 2005.. The Salt River Project reservoirs in Arizona are full and there are surplus state project waters available to Metropolitan Water District.

The winter of 2005/2006 is about average throughout the basin, but the spring is warm. April-July inflow to Lake Powell is 7.4 maf (95% of normal). Year to year storage in Lake Powell gains another 1.0 maf, but end of year storage still just short of the 14.85 maf interim equalization trigger. Lake Mead loses another 1.2 maf of storage. At the end of water year 2006, Lake Mead is at an elevation of 1,115' or 12,900,000 acre feet of storage.

Nevada is very nervous. It accelerates its plans to build a third intake to take water down to 950', but the project is expensive and there are water quality concerns.

The Basin States are continuing to meet. Technical committees are exploring better management strategies for Lake Mead and Lake Powell, how to address the Upper Basin's Mexican Treaty obligation and how to improve system efficiencies in the Lower Basin. Reclamation reminds the states that between Mead and the CRSP reservoirs, there is still over 30 maf in storage, a significant improvement over 2004. Modeling results suggest the chance of future equalization releases is greater than 80%.

Water years 2007 and 2008 are moderately dry, but summer rainfall in Arizona is well above average.

April-July inflow to Lake Powell for 2007 is 5.8 maf and 5.4 maf in 2008 (about 70% of average). Lake Powell loses 1.5 maf of storage but at the end of water year 2008, it still has 11.0 maf of storage. Except for shortages on local tributaries, water supplies in the Upper Basin are tight, but adequate. However, Lake Mead has lost another 2.4 maf of storage, 10.4 maf is available in storage (approximate elevation is 1,085').

The Secretary reminds the Basin States that the development of consensus shortage criteria is essential and gives the states a six month deadline. Nevada begins construction of a pipeline to move water from the Muddy River Basin to Las Vegas.

The Upper Basin States are frustrated that there is still no resolution of the Mexican Treaty obligation issues. Several of the Upper Basin States are nervous about pushing the issue too hard. Conditions in the Upper Basin are better than in the Lower Basin. Utah is trying to obtain necessary federal permits for a pipeline from Lake Powell to St. George.

Water year 2009 is a little wetter than 2008, but Lake Powell continues to lose about 1.5 maf of storage. 2009 is the ninth straight year Lake Powell has delivered 8.23 maf to Lee Ferry.

The Secretary assigns a mediator to help the Lower Basin States with consensus shortage criteria. The three Lower Basin States agree to take a 600,000 acre foot shortage. The shortage is managed by Arizona reducing deliveries to the groundwater bank and additional land fallowing along the Colorado River mainstem.

The Secretary announces that water quality at the border with Mexico is "technically" not in compliance with minute 242, but this is just a temporary problem. The Secretary asks the Basin States to propose a solution. The State Department suggests that Mexico should accept the lower quality water in return for not taking a shortage. Reclamation announces that the Yuma desalter will begin operating at 40% capacity.

2010 continues dry, Lake Powell loses another 2.5 maf of storage. The Lower Basin struggles through another year with 1.0 maf of shortages. The Salt River Project reservoirs in Arizona and the Metropolitan Water District's East Side Reservoir are at critically low levels.

By 2012, the continued drought has drained Lake Powell below minimum power. The Secretary concludes that Lake Powell cannot deliver 8.23 maf, but only 5.0 maf. Total deliveries from the Upper Basin to the Lower Basin, including for Mexico, from 2003 through 2012 are 79 maf.

The Lower Basin States take the position that the Upper Basin is in violation of the 1922 compact and must curtail depletions (a compact call) and deliver another 3.0 maf of water to Lee Ferry.

The Upper Basin States respond that because there has never been a resolution of the Mexican Treaty obligation, its III (d) deliveries are still 4.0 maf over the minimum 75 maf.

Lawsuits are filed in the Federal District Courts in both Utah and Arizona. Ultimately, there is state to state litigation in the United States Supreme Court.

A Federal Court in Arizona orders the Secretary not to approve any contracts or permits for additional Colorado River depletions pending settlement of all legal cases.

A group of farmers in Arizona files a suit in the Federal Claims Court claiming that the interim shortage criteria have "taken" their water rights without compensation. The farmers ask for $2.7 billion in damages.

A large Indian nation in Arizona files an action for quiet title to 800,000 acre feet of Colorado River water under its reserved rights. It claims a pre-1900s priority date.

An environmental group in Utah files a lawsuit to prevent the Secretary from refilling Lake Powell. Reclamation is concerned with geologic conditions on the left abutment of Glen Canyon Dam that have been exposed by the drawdown. They are very concerned, but express confidence that the dam can be refilled as long as the situation is "carefully monitored."

2013 and 2014 are wetter, but only about average. Reclamation decides to limit the refill of Glen Canyon Dam while it monitors the situation.

The litigation continues on all fronts. After about 18 months of procedural skirmishes, the Chief Justice of the United States Supreme Court appoints a special master. The master is a well respected attorney, but has spent the bulk of his career practicing law in northern Virginia.

The Secretary assigns a special mediator to meet with the Basin States. The mediator has just completed an assignment on the settlement on a border dispute between India and Pakistan.

The President of the United States asks each of the Basin States governors for their cooperation in finding a settlement.

Senators from Nevada and Arizona introduce legislation to amend the 1968 Basin Act to repeal provisions of the Act that require the Central Arizona Project and Southern Nevada Water Authority projects to be subordinate to California.

A member of the House of Representatives from California introduces legislation to repeal Congressional approval of the 1922 and 1948 compacts and instruct the Secretary to administer the entire Colorado River under the prior appropriation doctrine based on the dates project water was first used. The other 59 members of the California delegation (after reapportionment in 2010) sign on as cosponsors.

A senator from Wyoming introduces legislation to return the lands acquired under the Gadsden Purchase to the Republic of Mexico.

A state court in Arizona rules that deliveries of water to Mexico under the 1944 treaty is a national obligation and orders the Secretary of the Interior to begin construction of a project to divert water from the Snake River Basin in Idaho and northwest Wyoming into the Colorado River Basin for delivery to Mexico.

A Washington D.C. based think tank formed by a former Speaker of the House issues a report addressing the water problems in the Colorado River Basin. The report assigns 100% of the blame for the messy situation on the socialist policies of the Democratic Party in the 1930s, 1950s and 1960s.

The report claims that the residents of the Basin and the entire Nation would have been better off today had the Federal Government not subsidized the construction of Hoover Dam, Glen Canyon Dam, the Central Arizona Project, Central Utah Project, Colorado-Big Thompson Project and all other Reclamation projects in the Colorado River Basin.

The report suggests that had the policy been to allow only private development for water projects in the Basin, there would have been an ample supply of low cost water available for all uses.

The Secretary's special mediator gets an agreement among the governors of the seven Basin States to appoint special negotiators to address compact issues and possibly renegotiate the compact under Article VI of the compact.

The Colorado Senate passes a resolution instructing its compact negotiator to accept no less than 50% more water than what Colorado previously received under the 1922 and 1948 compacts.

FINALLY, at the third scheduling conference with the Master, he tells a story about a fishing trip he took a few years ago on a reservoir on the Colorado River. At the end of the story, he asks the United States attorney to again remind him why Texas is not a party to this case, because from what he remembers, Lake Travis is just north of Austin.

The process continues, the mediator proposes as a compromise, the Upper Basin States will deliver 8.0 maf per year at Lee Ferry, but only uses after 2016 would be subject to a call. Question; do the Upper Basin States accept the offer or do they contemplate secession from the Union?